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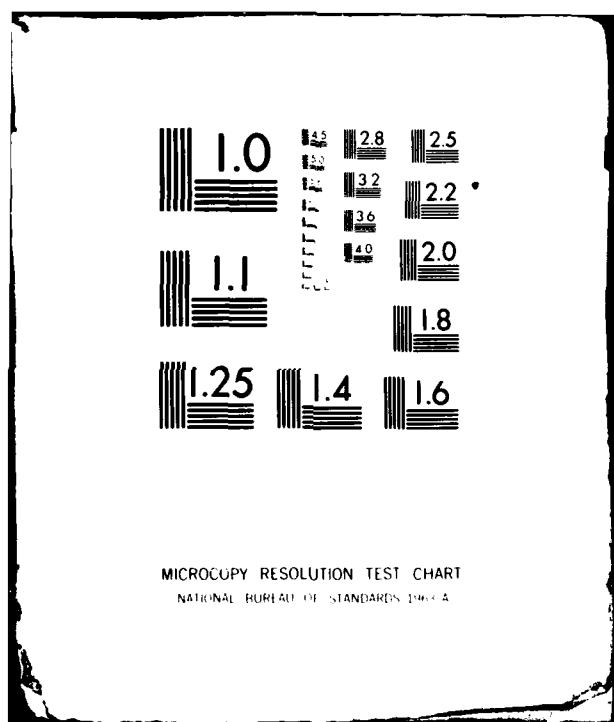
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DESIGN OF A UNIQUE AZIMUTH MONITORING DEVICE

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INTRODUCTION

This is an outline description of an experiment designed to monitor changes in relative azimuth (translation and rotation) between widely separated points; points possibly located on differing geologic materials.

I. Significance of the Experiment to the Air Force:

As missile CEP's get progressively smaller, there is an increasingly urgent requirement to monitor all of the geokinetic effects acting upon the missile launch site, the missile alignment systems, and affecting missile weapons system accuracy.(1) (2) It is therefore necessary to devise a means to monitor the translational and rotational changes of the crustal environment around a missile launch area. This must be done to determine the magnitude, frequency, and elasticity of azimuthal movements as they affect missile accuracy. This experiment is designed to be a simple simple first look at automatically monitoring direction and magnitude changes in azimuth to determine those phenomena affecting such an azimuth change.

II. Statement of the Problem:

Relativistically, ambiguities exist in measurement of movements between between two stations. Figure 1 shows in plan view the problem in trying to

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sort out the various movements of two unconnected stations. This experiment will monitor the relative horizontal movements of two stations and differentiate between the several possible combinations of movements. The positions of the stations will be monitored by the use of optical "ties" between the stations.

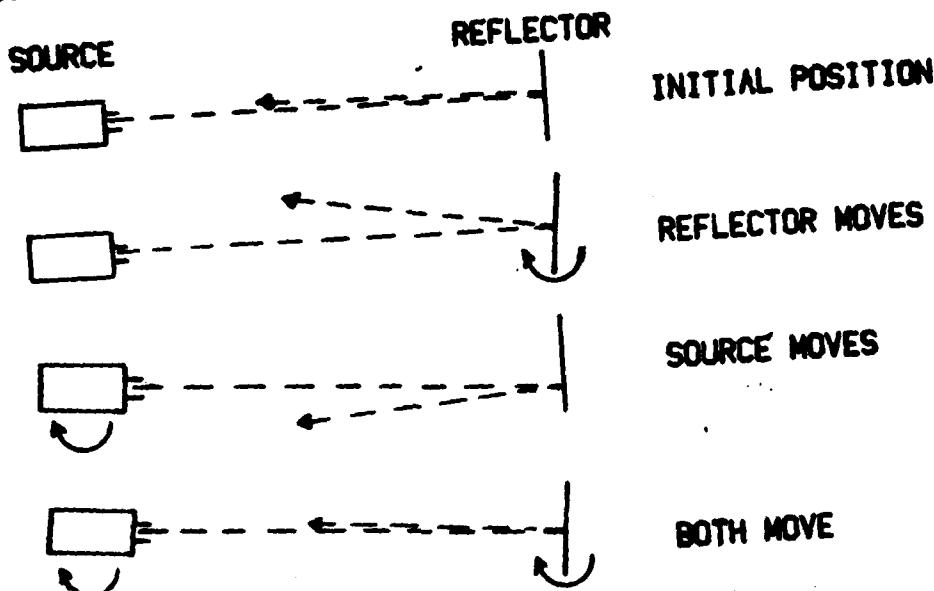


Figure 1

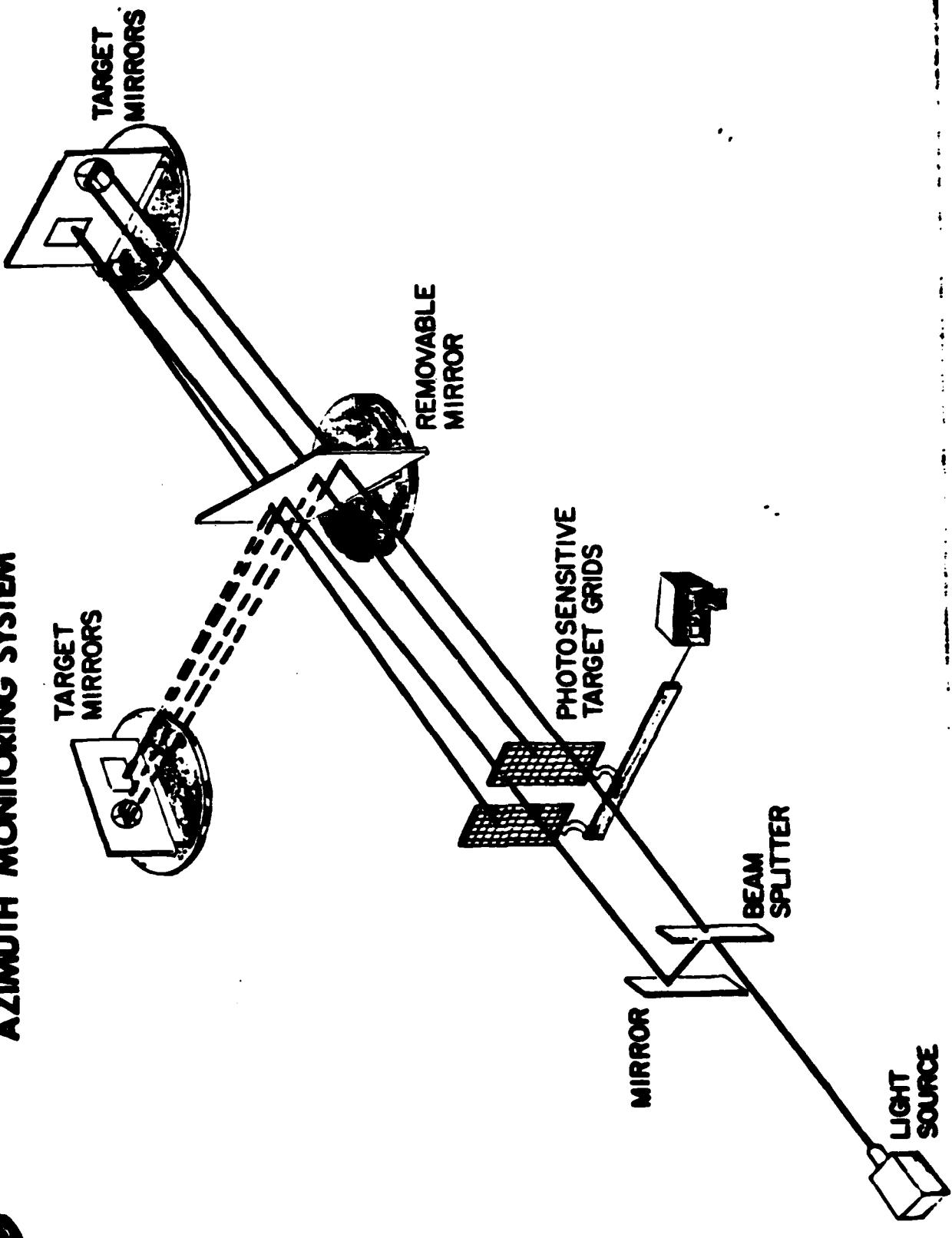
III. Description of the Experiment:

The test equipment consists of a sending/receiving site; a redirecting mirror site and two reflecting sites. (Figure 2) The receiving site will have a light source, beam splitter and mirror which will direct two beams (in close proximity to the receiving photomultipliers or image dissectors, if these are the receiving sensors) to the target mirrors. A modulated laser is employed as light source for this experiment to minimize the interference arising from ambient light. The receiving sensors and data recording equipment are also at the transmitting/receiving site. It is

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AZIMUTH MONITORING SYSTEM



hoped that for field use, the transmitting equipment can be mounted on a plate which will also accommodate a theodolite (Wild T-4 or similar) to permit periodic astronomic verification of azimuth.

Directly in the path to one of the target mirrors and connected to the transmitter site is a removable redirecting mirror. This mirror permits alternate measurements between a target mirror on a direct line-of-sight with the transmitter and one at an angle, say of 90°. Inclusion of a second target area permits detection of transmitter site movements and also aids in detection of down-range translatory movements on the part of the on-line target mirrors or the transmitter. These two effects cannot be determined with certainty from a single transmitter and target combination.

The target mirror sites each consist of a combination of a plane front-surface mirror and a roof prism or prismatic reflector. These are mounted such that the apex of the prism, mounted vertically, lies in the plane of the mirror's reflecting surface. (Figure 3)

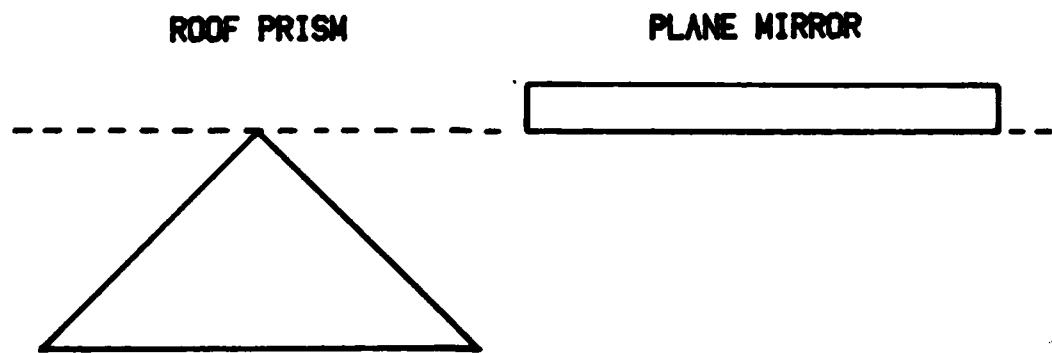


Figure 3

The reflected rays are directed back to the transmitting site, where photo-sensitive equipment monitors the movements of the light images. The initial configuration of the experiment is set up on a monolithic pier in the AFGL laboratory area. The prototype is being used to determine resolution and repeatability of the measuring device.

For later experiments, this equipment will be set up in an area where earth tilt is being observed to determine if there is any correlation between the tilting and the azimuthal changes.

An observing area has been selected close to the AFGL facility in Bedford, Massachusetts, close to a tiltmeter array site. Pillars will be constructed to accept the observing equipment and the targets with a minimum of thermal inequalities at the contact areas of dissimilar materials. A horizontal survey of the observing pillars will be made to establish the scale factor of the experiment. Available instruments will monitor the weather conditions, temperature, pressure and humidity and wind on site during the measuring processes. The equipment will be placed in operation and test measurements will be made to determine if variations in the integrated image locations can then be used to determine the relative motions between the three stations.

Then the experiment will be used in an attempt to statistically produce an image center and record this image center with enough precision and repeatability to measure its relative motions accurately to tenths of an arc second. Should this prove feasible, the experiment will proceed toward development of means of taking the centering signal from the image dissector, giving it

a digital value and developing the angular determination between two or more similar remote target sites.

IV. Geometric Considerations:

It is interesting to consider the geometry of the various possible motions:

Type of Motion

Initial Position

Cross Range Translation
(Reflecting Site)

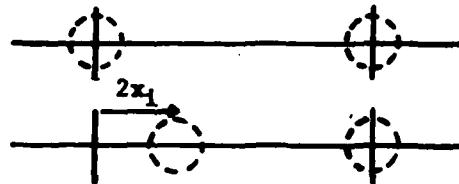
Cross Range Translation
(Transmitting Site)

Rotation, Reflecting Site

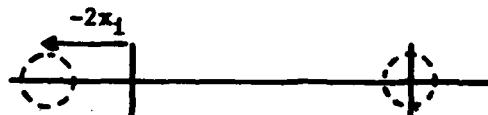
Image Configuration at Receiver

Prism Image

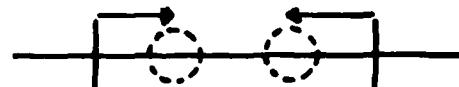
Mirror Image



Mirror image motionless. Prism image moves in the direction of the translation and twice the amount of translation. ($2 x_1$)



Mirror image motionless. Prism image moves ($-2 x_1$) opposite to translation.



Mirror image will move
($2S \sin \Delta\theta_1$)

= incidence angle

Prism image will move

$S \cos (\pi/2 - \Delta\theta_1)^*$

S = distance between center of incidence of beam on mirror and receiver.

(*The unique case where the pivot point is down the axis of the roof prism or prismatic reflector would cause the prism image to be motionless while the mirror image moved ($2S \sin\Delta\theta_f$)).

Rotation, Transmitting Site



Mirror image moves ($S \tan\Delta\theta_f$).

Prism image will move $S \cos(\pi/2 - 2\Delta\theta_f)$.

Down range translation, by itself, will not be recorded as an azimuth change on a single line-of-sight observation.

Admittedly, this is a naive listing of ideal singly occurring events. In reality there would be some combining of these motions. In fact, one main ambiguity is caused by reinforcing movement, rotational or translational, by one site with respect to the other. However, the need for such a monitoring capability is great enough to justify a start in this direction.

V. Measurements:

The quantity being measured in the plane mirror and the prismatic reflector for cross-range translation of either the sending or receiving station is Δx , where Δx is the cross-range displacement. Because the translation reflected in the prismatic reflector's geometry of translation is $2x$, the actual quantity measured is $42x$ or 2 times the translation. This can be seen from the

the fortunate fact that if we look at the reflecting station in plan view, the prismatic reflector can be represented as a right angle or a right triangle with its apex bisected by the optical axis of a line parallel to the transmitted light beam. Any deflection within the prismatic reflector or, if it is a hollow corner cube, from the first to the second, to the third plane orthogonal mirrors, can be treated as a two-reflection problem when it has been treated in plan view of a two-dimensional representation of the situation. From this treatment it can be seen that any change, Δx , of the cross-range translation either of the sending or receiving station is immediately reflected back to the receiving station in the amount $2\Delta x$, or twice the displacement of the station. We have to consider these movements as they are quantities which in this experiment are our measuring parameters and upon which we will have to perform our error analyses before we determine the theoretical precision of our experiment. We have discussed the quantities which, for cross-range translation, fortunately are linear.

For the case of rotation of the receiving station, the movement of the reflected image at the receiving site is equal to $2S \sin\theta_f$ with θ_f as the angle of incidence with the plane mirror, and S is the distance between the mirror and receiver measured along the light beam. The movement of the image from the prismatic reflector caused by rotation of the receiving station is equal to $S \cos(\pi/2 - 2\theta_f)$.

For the situation of rotation of the transmitting site, the displacement of the image as received at the receiving site is for the plane mirror equal to $S \tan(2\theta_f)$ and for the prismatic reflector again it is equal to the quantity $S \cos(\pi/2 - 2\theta_f)$. Thus, we see that the quantity we are actually

monitoring is the change in the rotational angle $\Delta\theta_f$. The functions for that angle which are of interest are the sine, cosine and tangent. Therefore, the differentials of these are the cosine, sine, and secant squared, respectively. It is with these parameters that we have to construct our experiment.

VI. Data Acquisition:

The laser light beams travel a distance of 12 meters from the laser to the mirrors and back to the beam spot position sensors. These sensors are Schottky barrier photodiodes having a sensitive area 35 millimeters on a side. This device has four connections, one on each side. When a light image is centered on the photodiode, equal current is sensed at opposite terminals; this is the null point. As the centroid of the light image is moved away from the detector's null point a current imbalance occurs. This difference in current is proportional to the displacement of the image centroid from center position.(1) Because two sets of terminal contacts are used on these sensors, image motion is detected in two axes. The builder of our photodiode system describes the signal development as follows:

" Since the photodiode is a current source, the preamplifier is a current to voltage operational amplifier where the output voltage is $E_0 = IR_f$. The next stage is a difference amplifier which subtracts up from down or left from right voltage signals. The result is a voltage proportional to light spot displacement from center. This difference voltage, E_d , is also proportional to the light intensity so that if no corrective action were taken the gradient of the position measurement would vary with intensity, I . Fortunately the sum of the two currents is also proportional to intensity but not to light spot position changes. One straightforward solution then is to divide the difference by the sum to arrive at a signal proportional to position but not intensity:

$$K_3 E_{y,x} = \frac{K_1 E_d \cdot I}{K_2 E_s \cdot I} \quad " \quad (1)$$

The light source is a He-Ne laser, modulated at 400 Hz. Each of the photodiodes is optically filtered to reduce the effect of background light. The efficiency of the optical filter is 0.8 and the response of the photodiodes at 6328A is 0.8. The response to motion (image centroid motion) is $0.2 \mu\text{a}$ for 0.1 mm change.

So far, electronic noise from the sensors or preamplifiers has not been a significant factor in determining resolution. A more likely factor is the linearity of the operational divider. Supposedly, the dividers selected have inherent noise of less than 1 millivolt, making resolutions of 0.001 mm feasible. We know from breadboard calibrations that the response is nonlinear (Figure 4). However, it is consistently repeatable and the nonlinearity error (e) closely approaches

$$e = 0.01 (Y, X)^{2.4}.$$

Each of the analog signals from the photodiodes (Y rotation, X rotation, Y translation, X translation) is fed through an analog multiplexer to an analog divider. These signals are then passed to an incremental 7-track tape recorder.

VII. Tests Results:

A preliminary calibration of vertical translation (Y_t) has been performed. The reflecting mirror was incrementally displaced several millimeters in the vertical plane and the resultant voltage change was recorded at the sending/receiving site. Figure 5 is a calibration plot of Y_t where the solid and dashed lines represent different directions of movement. The linearity and repeatability of this plot are noteworthy.

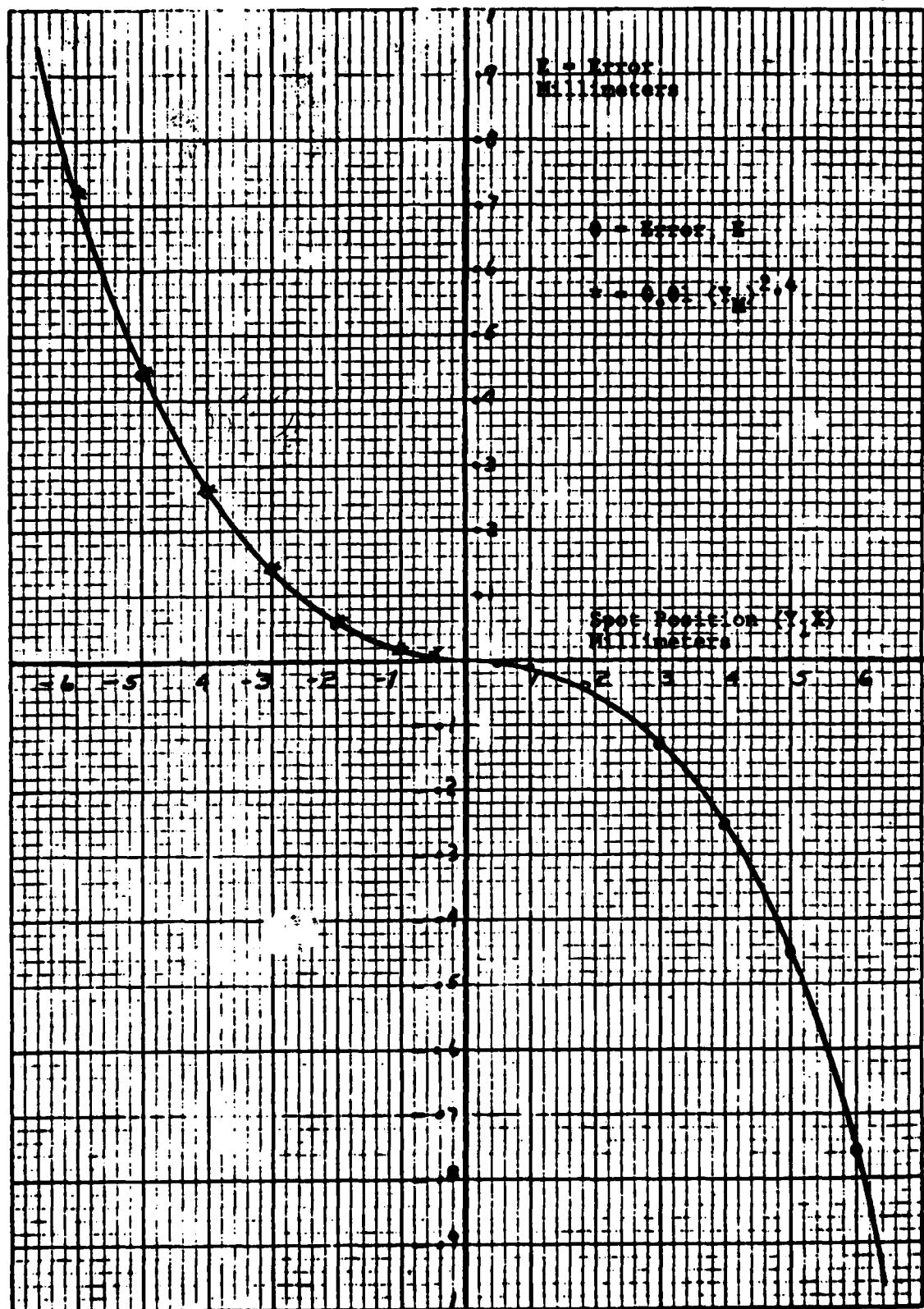


FIGURE 4 - NONLINEAR CHARACTERISTIC CURVE

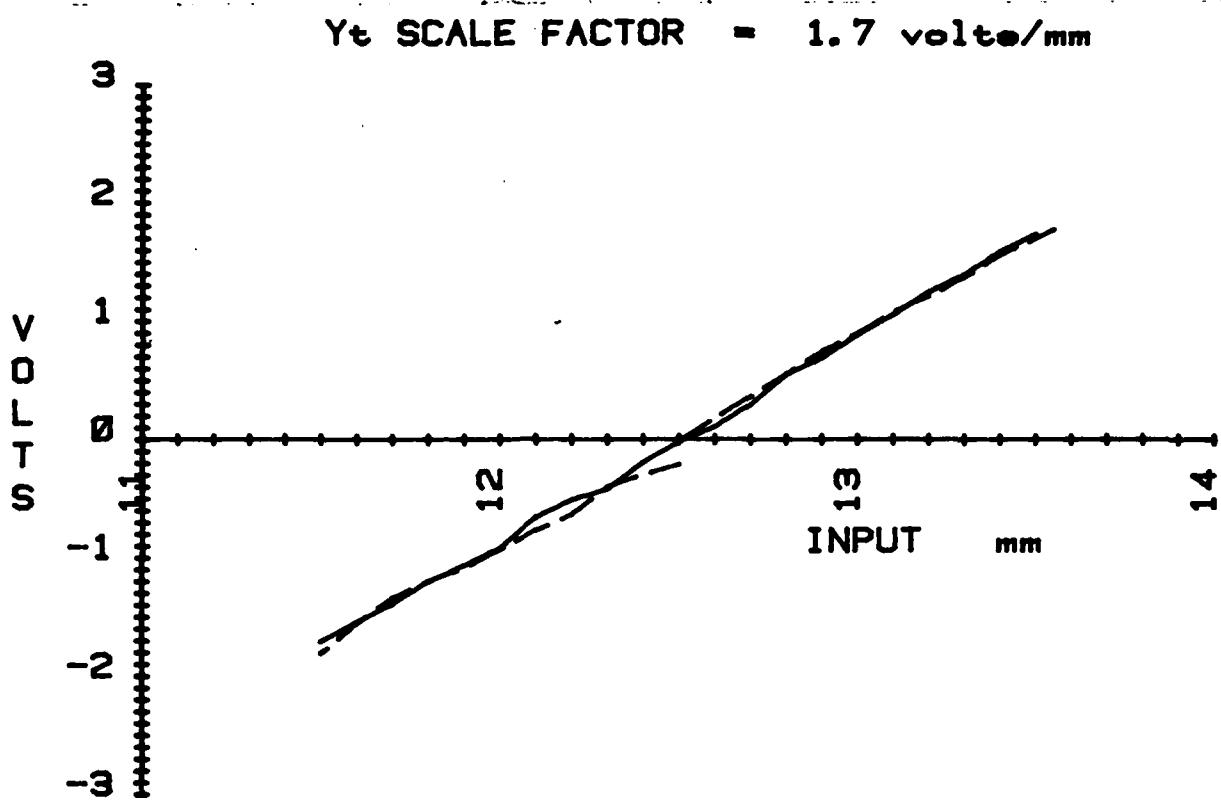


Figure 5

In addition, long-term stability tests have been performed on the system. For these tests the system was set-up and aligned with both the sending/receiving site and the reflecting mirror site located on the same isolated pier. The system was then left undisturbed for several days while data from all four parameters was recorded. Figure 6 is a plot of a typical 24 hour period. As would be expected, the vertical displacement (Y_t) of approximately 0.1 mm was larger than horizontal displacement (X_t). Future tests include calibration of all four parameters, as well as, both long (days) and short (hours) term stability tests.

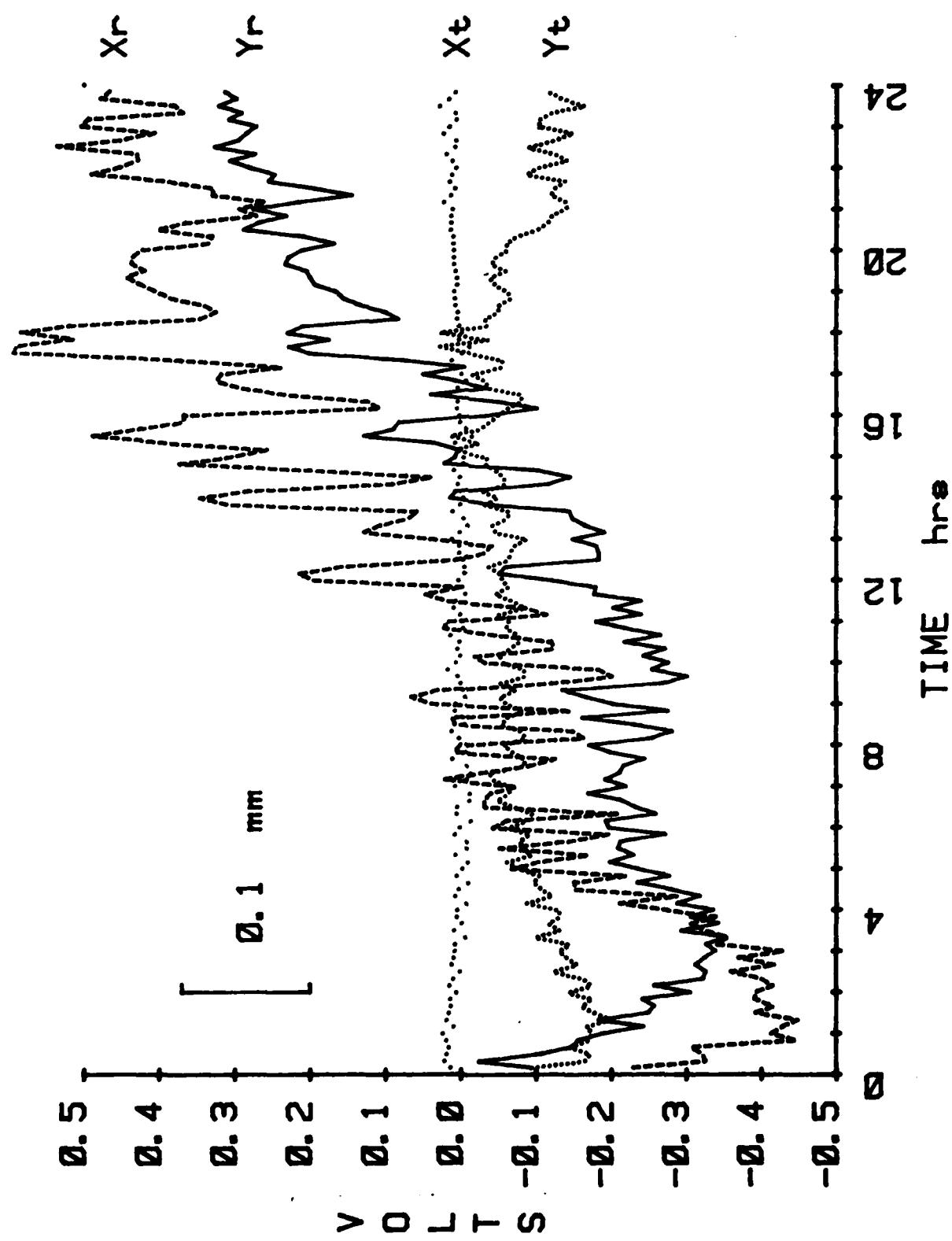


Figure 6

VIII. Conclusion:

This experiment offers a way to use electro-optical image monitoring as the means of determining the azimuthal change in a reference line which is so critical to proper missile alignment. This experiment is, as said before, offered as a first step in this direction and will be concerned chiefly with the ability of the instrument to detect any apparent rotational and translational movements present in the test site and then hopefully to quantify these prior to moving on to the more sophisticated multiple station and absolute azimuth reference portions of the experiment.

Future steps envisioned are the addition of a multiple reflection of an observation to compare movements more accurately between stations, where with one light beam you go directly to a light station and have the light reflected directly back. By a different path a beam is reflected at an intervening station out to another observed station and back by the way it came to serve as a check on the apparent movement of either or both of the target stations. A third phase of the exploration will consist in the study and exploration of ways to add an absolute azimuth reference to this particular type of measurement. As can be seen from the above, the experiment places no reliance on personal biases entering in as there are no manual optical observations necessary once the equipment is aligned and in operation.

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- (3) Morse, E. P., "A Dual Electro-Optical Light Image Receiver and Recorder", AFGL-TR-77-0002, January 1977.

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and is currently undergoing evaluation at the Air Force Geophysics Laboratory. The device is designed to monitor changes in relative azimuth (translation and rotation) between widely separated points. The test equipment consists of a sending/receiving site; a redirecting mirror site; two reflecting sites; and a modulated laser.

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